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Atmospheric correction of coastal hyperspectral remotely sensed data is a difficult problem. The subtle yet variable signals found in these areas do not lend themselves to traditional techniques of selecting atmospheric correction parameters. The procedures investigated not only address how to select these parameters given ground truth data, but also suggest ways in which atmospheric correction can be done completely remotely. In addition to the development of operational atmospheric correction algorithms for coastal hyperspectral remote sensing data, calibration procedures, specifically stray light characterization, was also explored. Finally, the development of a web based hyperspectral data delivery systems was produced.

Coastal Imaging Spectroscopy

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LONG-TERM GOALS

The hope of coastal HyperSpectral Imaging (HSI) data is that it will provide the necessary data stream to simultaneously describe the atmospheric and water column optical properties. However, the success in achieving this goal is contingent upon the sensitivity and precision of the calibration of remote sensing instrumentation deployed. Building upon the progress achieved in the calibration of PHILLS 2 hyperspectral instrument, we hypothesize that this data stream will provide the spectral and spatial resolution necessary to invert the calibrated remote sensing reflectance and water-leaving radiance to depth-distributed IOP's and optical constituents.

OBJECTIVES

1) Analysis and application of different atmospheric correction techniques on the PHILLS 2 calibrated spectral remote sensing data.

2) Development of optimization algorithm to derive depth-dependent optical properties.

3) Evaluation of optimization and look-up-table algorithms for real-time, or near real-time processing capabilities.

APPROACH

The optically complex coastal environment has proved to be difficult to work with in order to achieve successful classifications when using traditional multispectral remotely sensed data streams[1, 2]. The limited degrees of freedom available within these traditional data sets are not adequate for accurate environmental characterization. On the other hand, hyperspectral remote sensing data, with its numerous, narrow, contiguous wavebands, approximate the true electromagnetic signature of its target [3]. As part of an ONR Environmental Optics program and NRL program (Code 7212), we have developed the tools, techniques, and collaborations to calibrate and deploy two hyperspectral imaging spectrometers, the PHILLS 2 and SAMSON [4, 5], that produce hyperspectral remote sensing data at

the signal-to-noise level necessary for coastal ocean imaging spectroscopy [5]. This effort has led to a radiometric calibration technique that does not require the use of subjective tuning parameters to retrieve upwelling radiance at the sensor from raw digital count data.

Through our numerous field deployments, we have demonstrated that spectral integrity and quality of the data is directly dependent upon instrument design, calibration, and deployment techniques. While the importance of radiometric calibration cannot be over-emphasized, the removal of the atmospheric effects found within the data can not be ignored. The ocean is a dark target, whose spectral reflectance must propagate through a bright atmosphere. At high altitudes, the radiance at the sensor is mostly reflected by the atmosphere (90-99%)[6]. The disproportionate influence that the atmosphere has on the observed signal dictates that the removal of its effects is handled sufficiently prior to the application of any remote sensing algorithm.

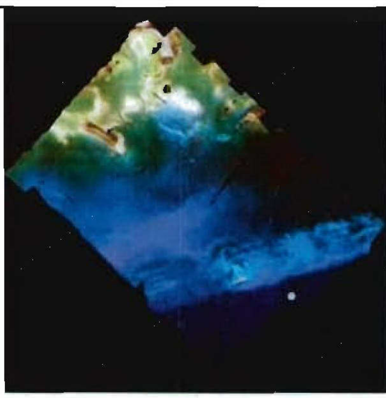


Figure 1: A PHILLS II, three band mosaic of the Looe Key site. Location of ground truth is denoted with the blue dot.

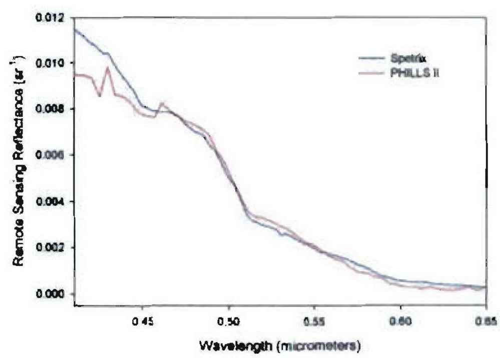


Figure 2: The comparison of the best GA TAFKAA corrected PHILLS II data and the ground truth data.

Parameter Name	Range	Selection
Water Column Vapor	[.5, 3.0]	1.980
Ozone	[.246, .248]	0.247
Aerosol Optical Thickness (Tau 550)	[.05, 1.5]	0.05
Wind Speed	[2, 6, 10]	2
Relative Humidity	[50, 70, 80, 90, 95]	98%
Aerosol Model	[urban, maritime, coastal, coastal-a, tropospheric]	tropospheric

Table 1: The parameters for the Looe Key, FL (October 31st 2002) derived using the genetic algorithm coupled with NRL's atmospheric correction program, TAFKAA.

2003 - WORK COMPLETED and RESULTS

Remote sensing algorithms assume that the effects of the atmosphere have been properly estimated and removed from the data signal prior to their application. Atmospheric effects account for nearly 90% of the remotely-sensed signal over oceanic waters. The disproportionate influence that atmosphere has on the observed signal dictates that the removal of its effects be handled appropriately. The work to date on this project revolves around the development of atmospheric correction strategies for hyperspectral imagery. This work is an extension of the atmospheric correction work funded under Award N00014-00-1-0514.

The NRL developed atmospheric correction model, TAFKAA, was chosen to process the PHILLS II data stream. TAFKAA is a derivation of ATREM, the standard atmospheric correction model for hyperspectral remote sensing datasets. To increase the efficiency of its application, TAFKAA utilizes sets of predetermined tables. Guided by the solar and sensor geometries and environmental conditions, it returns a solution, which it applies to the dataset. The sensor and solar geometries are directly derived from the data's time stamp and positional information. The environmental conditions, on the other hand, need to be selected by the user. The parameters that TAFKAA utilizes are: ozone concentration, aerosol optical thickness, water vapor, wind speed, aerosol model, and relative humidity. Although there are instruments that measure these parameters, often the instruments or the knowledgeable personnel needed to run them are not available.

Rather than making educated guesses at the parameters' values, a genetic algorithm was developed (GA) to aid in the selection. The GA intelligently searched the parameter space by testing different

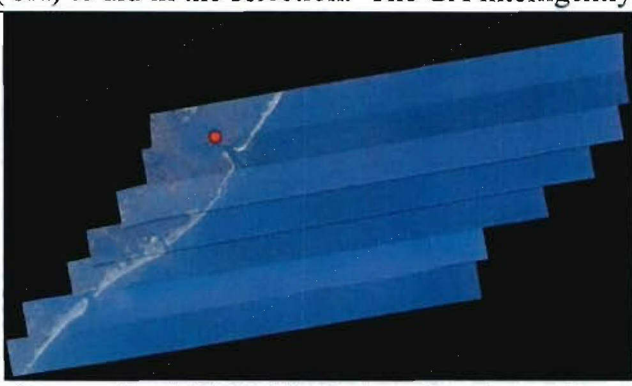


Figure 3: A PHILLS II, three band mosaic of the LEO 15 site in Tuckerton NJ. Location of ground truth is denoted with the red dot.

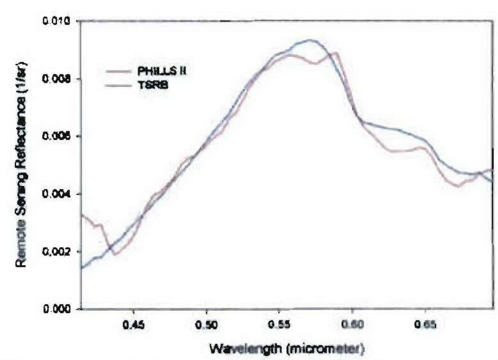


Figure 4: The comparison of the best GA TAFKAA corrected PHILLS II data and the ground truth data.

Parameter Name	Range	Selection
Water Column Vapor	[.5, 3.0]	0.5249
Ozone	[.30,.45]	0.339
Aerosol Optical Thickness (Tau 550)	[.05, 1.5]	0.166
Wind Speed	[2, 6, 10]	2
Relative Humidity	[50, 70, 80, 90, 95]	70%
Aerosol Model	[urban, maritime, coastal, coastal-a, tropospheric]	urban

Table 2: The parameters for the LEO -15 Tuckerton, NJ (July 31st 2001) derived using the genetic algorithm coupled with NRL's atmospheric correction program, TAFKAA.

combinations of atmospheric constraints. Prior to starting, a region of interest (ROI) is selected in the radiometrically corrected imagery that corresponds to the location of the ground truth station. The size ROI selected is on the order of 100 pixels. It is important to make the ROI large enough so to reduce the influence of randomly occurring errors. Randomly selected parameter sets are then evaluated by running the ROI through TAFKAA and comparing the spectral mean of its output to ground truth data. Parameter sets that produced results that resembled the ground truth data were maintained and evolved; the remaining sets were eliminated.

Due to the discretization of the parameter space for the GA, there were nearly 75 million possible solutions to test. Many, however, are unrealistic. The GA tested only about one quarter of one percent of the total possible outcomes. But in doing so it determined a realistic atmospheric model that produced PHILLS II remote sensing reflectance values that closely resembled the ground truth spectra. This approach has been used to determine the parameter selection at two of the PHILLS II deployment sites: LEO 15 Tuckerton, NJ and Looe Key, FL (see Tables 1 and 2 and Figures 1 through 4).

While the fitness between the ground truth spectra and the PHILLS II remote sensing reflectance are in both cases remarkably close, upon examining the history of the rejected parameter sets an issue emerges. There are numerous combinations of parameters that produce acceptable results; however, only one is good enough to make the final selection. This suggests the possibility that sensor or model flaws may play undue influence in developing of the selection. To address this, we have expanded our model to incorporate several ground truth sites at once. In doing so, however, an assumption of a homogeneous atmosphere for a particular day across the study sites had to be made. This approach has been run on the October 17th, 2002 San Luis Bay, CA study site (see Table 3 and Figures 5 and 6).

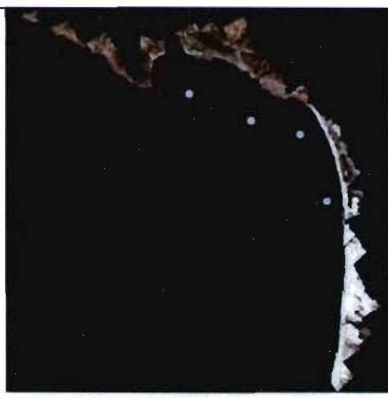


Figure 5: A PHILLS II, three band mosaic of the San Luis Bay, CA site. The locations of ground truth is denoted with the blue dots.

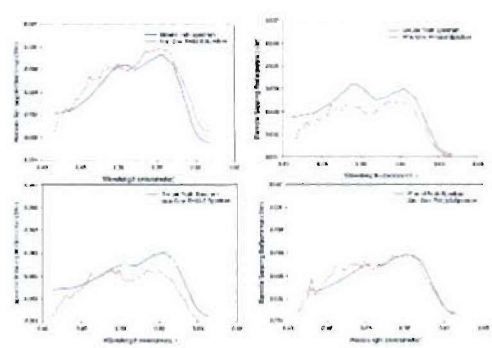


Figure 6: The comparison of the best multi-GA TAFKAA corrected PHILLS II data and the ground truth data.

Parameter Name	Range	Selection
Water Column Vapor	[.5, 3.0]	1.575
Ozone	[.30,.45]	0.3015
Aerosol Optical Thickness (Tau 550)	[.05, 1.5]	0.137
Wind Speed	[2, 6, 10]	2
Relative Humidity	[50, 70, 80, 90, 95]	80%
Aerosol Model	[urban, maritime, coastal, coastal-a, tropospheric]	maritime

Table 3: The parameters for the San Luis, CA (October 27th 2002) derived using the genetic algorithm coupled with NRL's atmospheric correction program, TAFKAA.

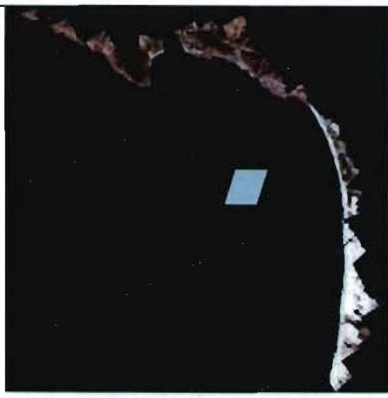


Figure 7: A PHILLS II, three band mosaic of the San Luis Bay, CA site. Location of area in which both water and atmosphere were determined to be invariant.

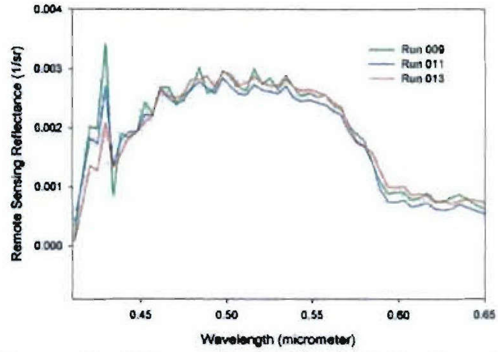


Figure 8: The comparison of the best GA TAFKAA corrected PHILLS II data.

Parameter Name	Range	Selection
Water Column Vapor	[.5, 3.0]	0.5249
Ozone	[.30,.45]	0.339
Aerosol Optical Thickness (Tau 550)	[.05, 1.5]	0.1805
Wind Speed	[2, 6, 10]	2
Relative Humidity	[50, 70, 80, 90, 95]	90%
Aerosol Model	[urban, maritime, coastal, coastal-a, tropospheric]	urban

Table 4: The parameters for the San Luis, CA (October 27th 2002) derived using the genetic algorithm with no ground support coupled with NRL's atmospheric correction program, TAFKAA.

Although we make every effort to have field support available when the PHILLS II is deployed, sometimes it is either logistically or financially prohibitive. We are currently working on two variations of the atmospheric GA to handle these situations. The first utilizes a "stacking" approach. This strategy requires the aircraft on which the PHILLS II is deployed to make a gradual, spiral descent over a homogeneous target area (i.e. deep water area). At different altitudes over the same ground ROI, separate data sets would be taken. Once atmospherically corrected, all of these data sets should be identical. Thus, rather than using the spectral difference as a measure of the parameters' fitness within the GA, the minimization of the spectral variation amongst the different data sets is employed. Although this approach has been coded, we do not yet have a data set to test it against. We hope to get one shortly.

The other method is based on the same premise. However rather than varying the altitude and thus atmosphere in which the sensor is exposed to, the time and corresponding solar geometry is allowed to vary. This approach depends on the selection within the collected imagery of a large area in which it is believed that both the atmosphere and water type are each invariant. Assuming this area is large enough to touch several flight lines, ROI's can be selected from each of these flight lines. Again once atmospherically corrected, the return of these ROI assumed to be identical. And thus, as was the case in the "stacking" approach, the GA is run employing a fitness derived from the spectral variation of the different ROIs. Although this approach is still in its developmental stages, it has produced some promising results on the San Luis Bay, CA image (see Table 4 and figures 7 and 8).

2004 - WORK COMPLETED and RESULTS

Last year's progress report outlined an automated atmospheric correction scheme that we had developed. The base of this approach is the NRL developed atmospheric correction model, TAFKAA. Guided by the solar and sensor geometries and environmental conditions, TAFKAA returns a solution, which it applies to the dataset. While the positional parameters are directly measured by PHILLS 2 instrument package, the environmental conditions must be supplied by another source. Rather than making educated guesses at the parameters' values, a genetic algorithm was developed (GA) to aid in the selection. The GA intelligently searches the parameter space by testing different combinations of atmospheric constraints. Prior to starting, a region of interest (ROI) is selected in the radiometrically corrected imagery that corresponds to the location of a ground truth station. The size ROI selected is on the order of 100 pixels. It is important to make the ROI large enough so to reduce the influence of randomly occurring errors. Randomly selected parameter sets are then evaluated by running the ROI through TAFKAA and comparing the spectral mean of its output to ground truth data. Parameter sets that produced results that resembled the ground truth data were maintained and evolved; the remaining sets were eliminated. Due to the discretization of the parameter space for the GA, there are tens of millions of possible solutions to test. Many, however, are unrealistic. The GA tests only about one quarter of one percent of the total possible outcomes. But in doing so it determines a realistic atmospheric model that produced PHILLS 2 remote sensing reflectance values that closely resembled the ground truth spectra.

This approach has been successful in atmospherically correcting many of our data sets. One of the more notable applications has the PHILLS 2 HyCODE flights over LEO 15 in Tuckerton, NJ. Results from the GA were presented in last year's report. Although the atmospheric correction over the ground truth station was a success, when the determined parameters were applied to the rest of the scene flaws in the data became apparent (Fig. 9). After some investigation, it was discovered that the magnitude of the flaws (the brightening at the center of the flight swath) were correlated with the zenith angle of the sun. It was speculated that the errors were caused by a reflection of light from within the cabin off the window that the sensor was imaging through. While the source of errors could not be directly accounted for, an iterative flat field approach that we developed was able to remove the effect (Fig.

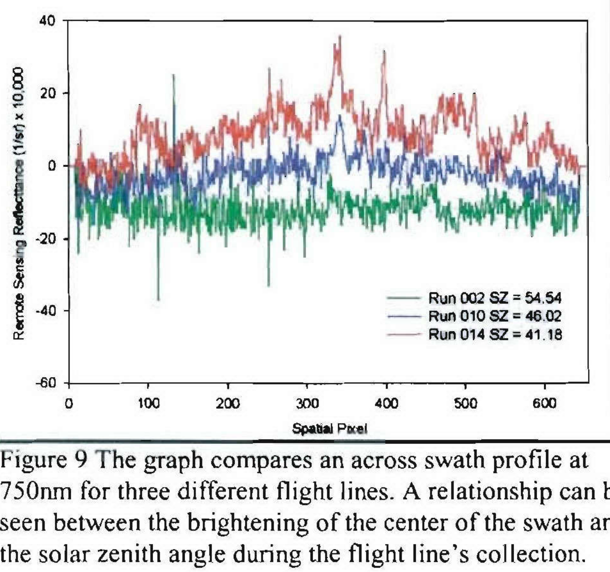


Figure 9 The graph compares an across swath profile at 750nm for three different flight lines. A relationship can be seen between the brightening of the center of the swath and the solar zenith angle during the flight line's collection.

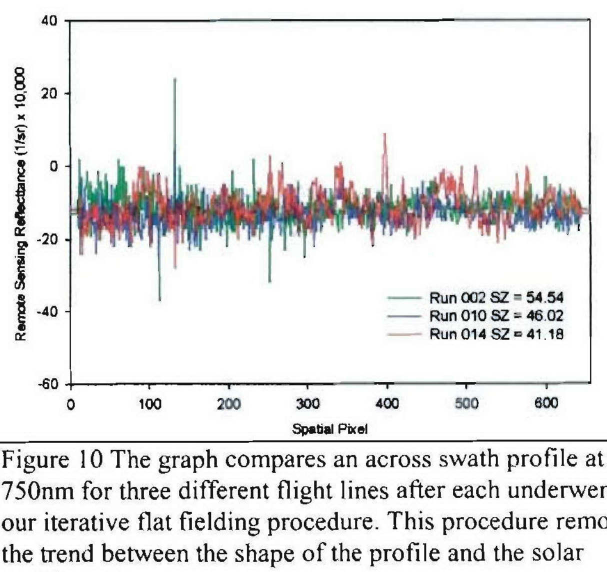
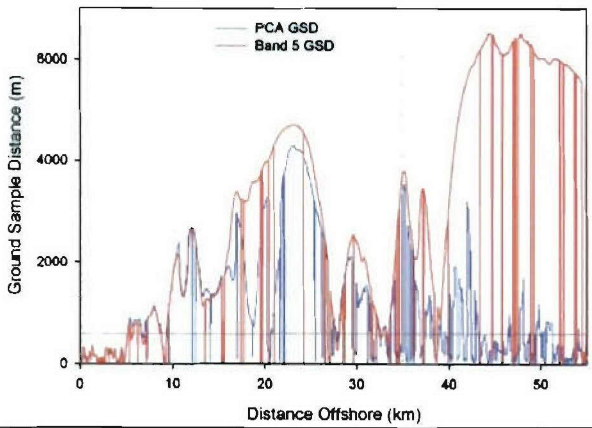


Figure 10 The graph compares an across swath profile at 750nm for three different flight lines after each underwent our iterative flat fielding procedure. This procedure removed the trend between the shape of the profile and the solar zenith angle.



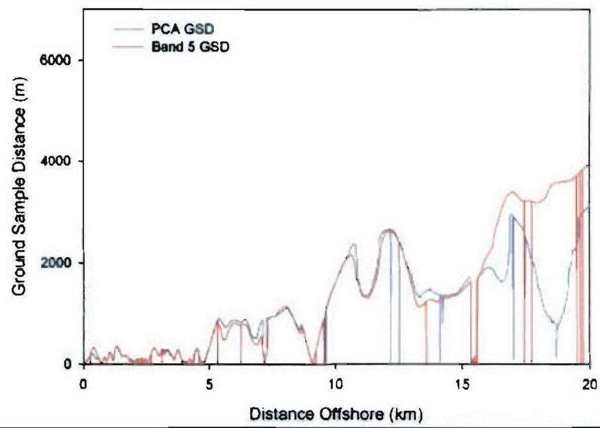


Figure 11 A graph of the maximum ground sample distance allowed before the variation within the sample exceeded the variation expect of a homogenous region and how that related to distance offshore. This analysis was applied to two data sets (an image that contains one band and an image that is a composite of the full hyperspectral signal). This comparison demonstrated that with both images the spatial heterogeneity was much higher near shore than off shore. However, it also showed more the subtle variability offshore was not detectable in images with limited spectral information.

Figure 12 A graph of the maximum ground sample distance allowed before the variation within the sample exceeded the variation expect of a homogenous region and how that related to distance offshore. This graph is zoomed in version of graph 3 and illustrates the agreement in maximum ground sample distance between the low and high spectral information images.

10). The corrected data along with the AVIRIS flight, which was collected at the same time, has been made available on the interactive data distribution site that we have developed (http://www.flenvironmental.org/HyDroDB/login.asp).

The atmospherically corrected LEO data set has produced useful insights into the spatial scales required to characterize the coastal environment. As outlined in Bissett et al.[7], we have developed a protocol to quantify the optimal ground sample distance (GSD) needed to resolve coastal and oceanic features (Fig. 11 and 12). While it is widely understood that the spatial heterogeneity increases the closer you are to the shoreline, this analysis gave the means to determine the degree of information lost in the selection of sensors with larger GSDs.

As has been outlined in previous reports (see ONR Award N00014-00-1-0514), the data set collected by the PHILLS 2 sensor during the LEO experiment was marred by an error that occurred during its installation within the aircraft. This flaw placed limits on how well the laboratory calibrations matched the sensor that was actually flown. Steps have been taken so that the installation error does not occur again. However, the physical stresses that the sensor witnesses during typical flights can affect the accuracy of the sensor's calibration. The results of these stresses become most apparent during the atmospheric correction of the data (Fig 13). In order to address this issue, we have expanded the Naval Research Laboratory's in-flight spectral calibration check [8]. We are in the process of finishing a program that automates their protocol. During the programs development, we have determined that in addition to their checks for spectral shifts the validity of spectral response function of the instrument must also be tested. We have added such a test to our procedure.

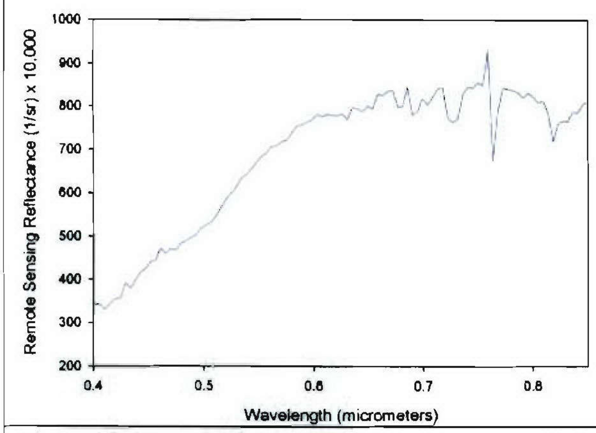


Figure 13 A graph of an atmospherically corrected, dry beach, sand pixel. The up-down spike witnessed near 0.760 micrometers is indicative of a spectral shift. The atmospheric correction program is attempting to remove the 0.762 micrometer oxygen absorption peak from the data and due to the spectral shift it has been misapplied.

The atmospheric correction of coastal hyperspectral data is difficult even under the most ideal conditions – clear weather and ample ground support measurements. While we make every effort to collect under these conditions, they are sometime not possible to achieve. Over the last year, we have been working on a "stacking" GA based atmospheric approach. This strategy requires that the aircraft on which the sensor is deployed to make a gradual, spiral descent over a homogeneous target area (i.e. deep water area). At different altitudes over the same ground ROI, separate data sets would be taken. Once atmospherically corrected, all of these data sets should be identical. Thus, rather than using the spectral difference as a measure of the parameters' fitness within the GA, the minimization of the spectral variation amongst the different data sets is employed. We have collected several test data sets from which to work with. The results are still preliminary; however, the procedure still looks promising.

2005 - WORK COMPLETED and RESULTS

We have continued the development towards an automatable atmospheric correction procedure for coastal hyperspectral remote sensing data sets. The base of this approach is the NRL developed atmospheric correction model, TAFKAA. Guided by the solar and sensor geometries and environmental conditions, TAFKAA returns a solution, which it applies to the dataset. While the positional parameters are directly measured by the PHILLS 2 and SAMSON instrument packages, the environmental conditions must be supplied by another source. Rather than making educated guesses at the parameters' values, a genetic algorithm was developed (GA) to aid in the selection. The GA intelligently searches the parameter space by testing different combinations of atmospheric constraints. Prior to starting, a region of interest (ROI) is selected in the radiometrically corrected imagery that corresponds to the location of a ground truth station. It is important to make the ROI large enough so to reduce the influence of randomly occurring errors. Randomly selected parameter sets are then evaluated by running the ROI through TAFKAA and comparing the spectral mean of its output to ground truth data. Parameter sets that produced results that resembled the ground truth data were maintained and evolved.

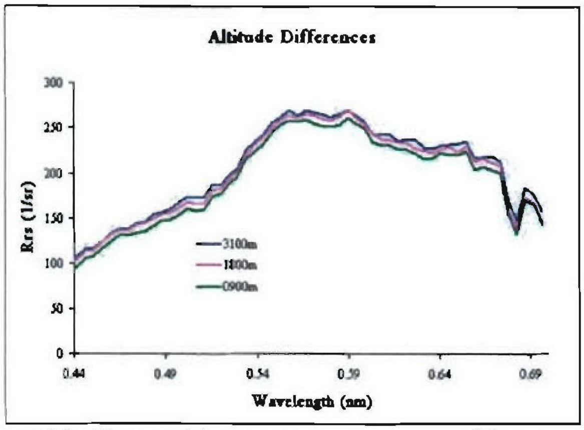


Figure 14. The resulting spectrum responses of the same target area when viewed from 3 different altitudes after the atmospheric effects were removed via the GA TAFKAA algorithm.

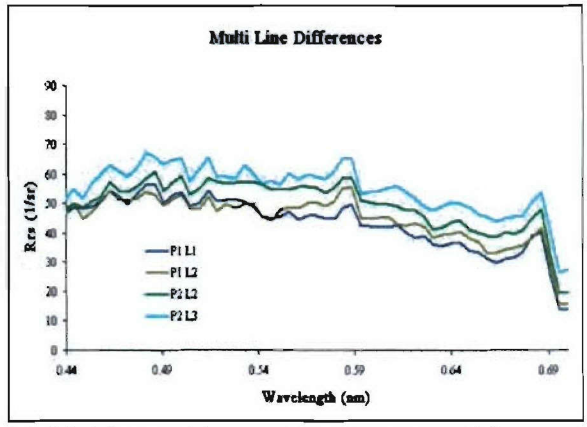


Figure 15. The resulting spectrum responses of the same target area when viewed from 4 different vantage points each taken at a different time after the atmospheric effects were removed via the GA TAFKAA algorithm.

The atmospheric correction of coastal hyperspectral data is difficult even under the most ideal conditions – clear weather and ample ground support measurements. While we make every effort to collect under these conditions, they are sometimes not possible to achieve. Over the last year, we have been perfecting a "stacking" and "overlap" GA based atmospheric correction approach (figures 14 and 15). The "stacking" approach requires that the aircraft on which the sensor is deployed to make a gradual, spiral descent over a homogeneous target area (i.e. deep water area). At different altitudes over the same ground ROI, separate data sets would be taken. Once atmospherically corrected, all of these data sets should be identical. Thus, rather than using the spectral difference as a measure of the parameters' fitness within the GA, the minimization of the spectral variation amongst the different data sets is employed.

The second approach, "overlap", follows a similar attack. However in this case, it uses the side-lap between flight lines in its comparison. Like the "stack", it follows the assumption that while the time and vantage point from which the measurements are taken is different, the true target remote sensing reflectance is the same.

Both of these approaches require a high level of confidence in the geoposition of the data. In an attempt to improve our geopositional abilities, we have partnered with Applanix Corporation, who develops survey grade inertial navigation systems. This partnership has led up to the development of high precision, orthocorrected (terrain corrected) hyperspectral products (figures 16 and 17). This partnership has also given us the opportunity to fly their high resolution digital camera in conjunction with our hyperspectral sensors. Not only does this produce fine resolution data products that compliment our hyperspectral data, but it is an independent measure of the atmospheric conditions. We are developing procedures to couple the two data streams to better address the atmospheric correction issues.

Neither the digital aerial camera nor hyperspectral sensor's data is of any use in tackling the atmospheric correction issue if there is little confidence in the radiometric integrity of their output. This year we have expanded upon our calibration and characterization activities of recent years by partnering with Steven Brown and Carol Johnson of NIST. The SAMSON instrument has undergone

Figure 16. A red-green-blue composite depicting a geopositioning error witnessed when using the previous geocorrection procedures.

Figure 17. A red-green-blue composite of the same area as was in figure 3 that depicting the improved geopositioning results derived by the new procedures.

extensive characterization at their facilities[7]. We are still in the midst of analyzing the data that was produced.

Also in previous year's reports, we have outlined procedures to correct for shifts between the camera and spectrograph components that have occurred between the time it was calibrated in the lab and flown in the field. In the development of SAMSON, we feel we have mechanically corrected the issue that had plagued PHILLS 2. However, in order to make the data sets collected by PHILLS 2 of better value we have expanded upon the idea outlined in previous reports to develop operational code that determines spectral response metrics, perceived spatial and spectral shifts, and smile and keystone adjustments. Much of this work is based upon the procedures outlined in Gao et al[8]. We have worked extensively with one of that paper's authors, Marcos Montes of NRL, in this development.

As outlined above, a significant amount of progress has been achieved in the development of a robust, operational data stream from the PHILLS 2 and SAMSON hyperspectral sensors. Characterization advancements, atmospheric correction algorithms, and the field/laboratory metrics produced will advance the usefulness of this data stream. These advances will allow for the real time or near real time promise of hyperspectral sensors to deliver environmental spectroscopy to be met.

In addition, we have made progress on our data delivery system (HyDRO - http://www.flenvironmental.org/HyDRO_DB/login.asp). The HyDRO user customizable experience has been expanded to allow the applications of algorithms to be applied to their requests. Algorithms that allow hyperspectral data mimic multispectral sensors have been implemented first; however, the code has been developed so that eventually users can supply their own algorithm modules.

IMPACT/APPLICATIONS

Atmospheric correction of coastal hyperspectral remotely sensed data is difficult problem. The subtle yet variable signals found in these areas do not lend themselves to traditional techniques of selecting atmospheric correction parameters. The procedures being investigated within this study not only address how to select these parameters given ground truth data, but also suggest ways in which atmospheric correction can be done completely remotely.

RELATED PROJECTS

This project has grown out of the ONR Award N00014-00-1-0514. As that project was, it is also closely coordinated with the ONR HyCODE (http://www.opl.ucsb.edu/hycode.html) and NRL Spectral

Signatures of Optical Processes in the Littoral Zone (Spectral Signatures) programs, as well as the C. Davis's ONR-funded research (N00014-01-WX-20684). It is also coordinated with P. Bissett's ONR funded research (N00014-01-1-0201) and C. Mobley's ONR funded research (N00014-D01-61-0001).

REFERENCES

1. Hu, C., K.L. Carder, and F.E. Muller-Karger, *How precise are SeaWiFS ocean color estimates? Implications of digitization-noise errors.* Remote Sensing of Environment [Remote Sens. Environ.]. Vol. 76, 2001: p. no. 2.
2. Lee, Z., et al., *Properties of the water column and bottom derived from Airborne Visible Infrared Imaging Spectrometer (AVIRIS) data.* Journal of Geophysical Research, 2001. **106**(C6): p. 11,639-11,652.
3. Chang, G., et al., *The new age of hyperspectral oceanography.* Oceanography, 2004. **17**(2): p. 16-23.
4. Davis, C.O., et al., *The Ocean PHILLS Hyperspectral Imager: Design, Characterization, and Calibration.* Optics Express, 2002. **10**(4): p. 210-221.
5. Kohler, D.D.R., et al., *A New Approach for the Radiometric Calibration of Spectral Imaging Systems.* Optics Express, 2004. **12**(11): p. 2463-2477.
6. Morel, A., *In-water and remote measurement of ocean color.* Boundary-Layer Meteorology, 1980. **18**: p. 117-201.
7. Brown, S.W., et al. *Spectral Irradiance and Radinace reponsivity Calibrations using Uniform Sources (SIRCUS) facility at NIST.* in *Eath Observing Systems IX.* 2004. Denver, CO: Society of Photo-Opticak Instrumentation Engineers.
8. Gao, B.-C., M.J. Montesa, and C.O. Davis, *Refinement of wavelength calibrations of hyperspectral imaging data using a spectrum-matching technique.* Remote Sensing of Environment, 2004. **90**: p. 424-433.

PUBLICATIONS

Mobley, C. D., Sundman L. K., Davis C. O., Bowles J. H., Downes T. V., Leathers R. A., Montes M., Bissett W. P., Kohler D. R. R., Reid P., and Louchard, E. *A spectrum matching and look-up-table approach to interpretation of hyperspectral remote-sensing data.* Applied Optics. Vol. 44. No 17. pp 3576-3592. (2005) [published, refereed]

Trees, C. C., Bissett, W. P., Dierssen, H., Kohler, D. D., Moline, M. A., Mueller, J. L., Pieper, R. E., Twardowski, M. S., Zaneveld, J. R. V., *Monitoring Water Transparency and Diver Visibility in Ports and Harbors Using Aircraft Hyperspectral Remote Sensing*. Proceedings of SPIE Volume: 5780. Photonics for Port and Harbor Security. SPIE (2005) [published]

Bissett, W. P., DeBra, S., Kadiwala, M., Kohler, D. D. R., Mobley, C., Steward, R.G., Weidemann, A., Davis, C.O., Lillycrop, J., and Pope, R., *Development, Validation, and Fusion of High Resolution Active and Passive Optical Imagery.* Society of Photo-Optical Instrumentation Engineers in Proceedings of SPIE Vol. 5809. (2005) [published]

Kohler, D. D. R., Bissett, W. P., Steward, R. G., and Davis, C. O. *A New Approach for the Radiometric Calibration of Hyperspectral Imaging Systems*. Optics Express. Vol. 12. No. 11. (2004) [published, refereed]

Bissett, W. P., Arnone, R., Davis, C. O., Dickey, T., Dye, D., Kohler, D. D. R., and Gould, R.. *From Meters to Kilometers - a look at ocean color scales of variability, spatial coherence, and the need for fine scale remote sensing in coastal ocean optics*. Oceanography. Vol 17. No. 2. (2004) [published, refereed]

Philpot, W. D., Davis, C. O., Bissett, W. P, Mobley, C., Kohler, D. D. R., Lee, Z. P., Snyder, W., Steward, R. G., Gould, R., and Arnone, R.. *Bottom characterization from hyperspectral image data*. Oceanography. Vol 17. No. 2. (2004) [published, refereed]

Chang, G., Mahoney, K., Briggs-Whitmire, A., Kohler, D. D. R., Lewis, M., Mobley, C., Moline, M., Boss, E., Kim, M., Philpot, W., and Dickey, T. *The new age of hyperspectral oceanography*. Oceanography. Vol 17. No. 2. (2004) [published, refereed]

Zhang, X., Lewis, M., Bissett, W. P., Johnson, B., and Kohler, D. *Optical Influence of Ship Wakes*. Applied Optics. Vol. 43. No. 15. (2004). [published, refereed]

Moline, M., Blackwell, S. M., Bissett , W. P., Kirkpatrick , G., Kohler, D. D. R., Sauer, M., and Schofield, O. *An autonomous platform for spatial ocean color validation*. Proceedings of Ocean Optics XVII. Fremantle, AU. (2004) [published]

Gould, R. W., Arnone, R. A., Sydor, M., Kohler, D. D. R., and Bissett, W. P. *Application of a near-infrared slope algorithm to derive optical properties from high resolution hyperspectral aircraft imagery*. Proceedings of Ocean Optics XVII. Fremantle, AU. (2004) [published]

Bissett, P., DeBra, S., Kadiwala, M., Kohler, D., Mobley, C., Steward, R., Weidmann, A., Davis, C. O., Lillycrop, J., Pope, R. *Development, validation, and fusion of high resolution active and passive optical imagery*. Proceedings of Ocean Optics XVII. Fremantle, AU. (2004) [published]

HONORS/AWARDS/PRIZES

2003 Small Business of the Year, Semi-Finalist, Florida Environmental Research Institute, W. Paul Bissett, Ph.D., Executive Director, Greater Tampa Chamber of Commerce.

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